Magnetic Fields in Irregular Galaxies

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Magnetic fields are an important component of the interstellar medium. They channel gas flows, accelerate and distribute energy from cosmic rays, and may be a significant component of the galactic pressure, especially in low-mass galaxies [1]. A priori, one wouldn't expect irregular galaxies to have large scale magnetic fields. The most common dynamo mechanism, the $\alpha - \omega$ dynamo, relies on differential rotation to stretch small scale fields into large scale fields [2]. Most irregular galaxies, however, are either solid-body rotators or show little rotation [3]. Despite this, observations of NGC 4449 [4] and the Large Magellanic Cloud (LMC) [5] have revealed the presence of large-scale magnetic fields in these galaxies.

Previous observations of a small number of irregular galaxies reveal a range of magnetic field properties. See Table 1 for a summary. Observations of the irregular galaxy NGC 4449 [4] show a strong large-scale field. Theoretical work has suggested that a bar and a fast dynamo are needed to reproduce the observed field structure [6]. The LMC has a weak large-scale field possibly generated by a cosmic-ray driven dynamo [5]. The magnetic field structures of NGC 6822 and IC 10 [7] are weak and almost completely random. The lack of a large-scale magnetic field in these galaxies may be caused by a combination of their intense star-formation and their lower rotation velocities [7].

The goal of this project is to significantly increase the number of irregular galaxies with observed magnetic field structures to better answer the following questions: (1) what generates and sustains large-scale magnetic fields in

irregular galaxies? and (2) what causes the range of observed magnetic field structure?

1 Measuring Magnetic Fields in Galaxies

There are many techniques for measuring magnetic fields [8]. We use diffuse synchrotron emission at centimeter wavelengths as a tracer of the magnetic field. High-resolution observations are crucial for minimizing the effects of beam depolarization. In general, the optimal observing frequency for these observations is 6 cm because there is low Faraday depolarization [9] at this frequency, but the synchrotron emission is still quite strong. The increasing strength of synchrotron emission at long wavelengths is neutralized by an increase in the amount of Faraday depolarization (which goes as roughly as wavelength squared) at these wavelengths.

We use the Very Large Array (VLA) and single dish radio observations from either the Green Bank Telescope (GBT) or the Effelsberg 100-m to obtain radio continuum polarization measurements of several irregular galaxies at three frequencies: 20 cm, 6 cm, and 3 cm. The VLA observations have the high resolution necessary for us to detect small-scale magnetic field structure, while the single dish observations allow us to correct the VLA observations for unresolved large-scale structure. Observing at 3 different wavelengths allows us to separate the free-free emission from the synchrotron emission and determine rotation measures.

We have selected galaxies that have a range of sizes, rotation rates, and star formation rates and that complement previous observations [4, 5, 7]. See Table 1 for a summary of galaxy properties.

2 Preliminary Results: NGC 4214 and NGC 1569

NGC 4214 has a slower rotation rate and weaker bar than NGC 4449 and a higher star formation rate per unit area. From the 6 cm VLA image of the continuum emission from this galaxy, we determined the amount of synchrotron emission using Hα images supplied by Deidre Hunter to estimate the thermal contribution to the 6 cm emission. There is very little polarized emission associated this galaxy. The total field in this galaxy is about $4\mu G$ and it is mostly random.

NGC 1569 has the highest star formation rate per unit area in our sample, and one of the highest star formation rates out of all galaxies in the local universe. It is possibly ejecting much its interstellar medium [10, 11] either through a pressure-drive, accelerating wind or a detonation.

Figure 1 shows a 6 cm VLA image of the synchrotron emission from NGC 1569 with vectors showing the orientation of the magnetic field and the intensity of the polarized emission. Again, we have used Hα images provided by Deidre Hunter to estimate the thermal contribution to the 6 cm emission.

X-ray observations [12] suggest that the northern half of the galaxy is tilted away from the line of sight, so it is not surprising that we do not see synchrotron emission from this half of the galaxy. The southern half of the galaxy, however, shows a wealth of features. An arm of synchrotron emission is seen on the western edge of the galaxy. Inside this arm, there is an Hα arm and inside the Hα arm, there is an X-ray arm [12]. The large scale magnetic field seen on the western arm is likely the result of a compression of gas or a shock. As gas is compressed, it drags the magnetic field along with it and amplifies the field. Most of the field lines in this galaxy are roughly perpendicular to the disk, except at the ends of the disk.

When we compare the 6 cm image to a 3 cm image, we see that the polarization vectors in the southern portion of the galaxy and along the western arm rotate very little between the two wavelengths. Based on the observed orientation of the fields between the two wavelengths, the rotation measure is constrained to be less than 32 rad m^{-2}. This result suggests that the line integral of the magnetic field along the line of sight times the thermal electron distribution is small.

The mostly random magnetic field structure of NGC 4214 closely resembles the magnetic field structure of NGC 6822 and IC 10. This galaxy probably does not have a strong enough rotation rate or bar to sustain a large-scale field. NGC 1569 has a large-scale magnetic field that appears to be shaped primarily by gas outflowing from the disk of the galaxy. The extent to which the magnetic field shapes or drives the outflow is the subject of further investigation. We are also reducing observations of NGC 1313 and NGC 1156 to add their magnetic field structures to the overall picture of magnetic field structures in irregular galaxies.

References

1. R. Beck: Magnetic Fields in the Milky Way and Other Spiral Galaxies. In: *How Does the Galaxy Work?*, ASSL Vol. 315, ed by E. J. Alfaro, E. Pérez, and J. Franco (Kluwer Academic Publishers, Dordrecht The Netherlands 2004) pp 277–286
2. R. M. Kulsrud: ARAA **37**, 37 (1999)
3. E. K. Grebel: Dwarf Galaxies in the Local Group and in the Local Volume. In *Dwarf galaxies and their environment*, ed by K. S. de Boer, R.-J. Dettmar, and U. Klein (Shaker Verlag, Aachen Germany 2001) pp 45–52
4. K. T. Chyży, R. Beck, S. Kohle, et al: A&A **355**, 128 (2000)
5. B. M. Gaensler, M. Haverkorn, L. Staveley-Smith, et al: Science **307**, 1610 (2005)
6. K. Otmianowska-Mazur, K. T. Chyży, M. Soida, and S. von Linden: A&A **359**, 29 (2000)
7. K. T. Chyży, J. Knapik, D. J. Bomans, et al: A&A **405**, 513 (2003)
8. E. G. Zweibel and C. Heiles: Nature **385**, 131 (1997)
9. B. J. Burn: MNRAS **133**, 67 (1966)
10. C. L. Martin: ApJ **506**, 222 (1998)

11. U. Lisenfeld, T. W. Wilding, G. G. Pooley, and P. Alexander: MNRAS **349**, 1335 (2004)
12. C. L. Martin, H. A. Kobulnicky, and T. M. Heckman: ApJ **574**, 663 (2002)

Table 1. Properties of Galaxies in Sample

Galaxy	Optical Extent kpc	$\log(SFR_D)$ $M_\odot$ yr^{-1} kpc^{-2}	$V_{max}/\sin(i)$ km s^{-1}	Bar?	$B_{uniform}$ μG	B_{total} μG
Previous Observations [4, 7, 5]						
NGC 4449	7×5	-2	110	strong bar	$6-8$	14
LMC	9.4×8	-2.9	50	yes	1	4.3
NGC 6822	2.3×2.0	-1.96	52	yes	< 3	< 5
IC 10	2.0×1.7	-1.3	30	no	< 3	5–15
Our Sample						
NGC 4214	10×8	-1.10	30	weak bar	~ 0	4
NGC 1569	2.1×1.0	0.11	40	yes	3–5	6
NGC 1156	7.5×6	-0.87	75	yes	?	?
NGC 1313	10.6×8.0	-0.78	89	strongest bar	?	?

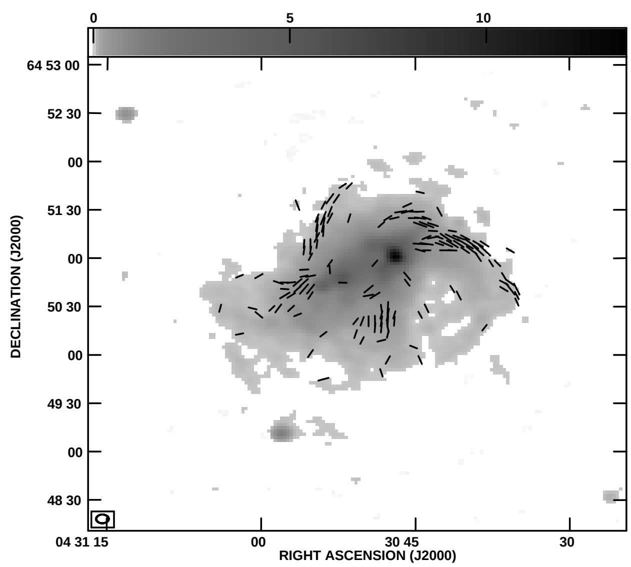

Fig. 1. Synchrotron emission from NGC 1569 at 6 cm overlaid with polarization vectors. The length of the vector indicates the strength of the polarized intensity ($1''$ is 5 μJy beam^{-1}) and the angle indicates the direction of the magnetic field.